Spatial structures of emerging hot and dry compound events over Europe from 1950 to 2023

J. Schmutz [1] (josephine.schmutz@lsce.ipsl.fr)
M. Vrac [1], B. François [2], B. Bulut [3]

[1] LSCE-CNRS, Gif-sur-Yvette, France [2] KNMI, De Bilt, The Netherlands [3] UKCEH, Wallingford, GB

Introduction

Hot and dry event :

- Is the combination of heatwave and drought, categorized as a **compound event (CE)**
- Has become more frequent over Europe in recent decades
- Impacts agriculture, health, biodiversity…

➢ **1. Have we already experienced changes in CE probabilities of occurrence? Where and when?**

➢ **2. What has driven them? Marginals or dependence?**

➢ **3. How does the non-stationarity dependence influence the emergence?**

Data

- **ERA5** dataset
- 0.25° x 0.25° over **Europe** and north Africa
- Summer (**JJA**) between 1950 and 2023

Heat index (T) : Monthly max of daily max t°

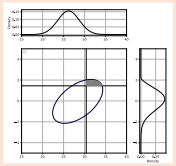
Drought index (S) : S=-SPEI6

Method

T and S are 2 random variables (CDF F_T and F_S), the **CE probability** is:

- $\boldsymbol{p} = P(T > T_e, S > S_e)$
  T_e and S_e are the 95^{th} percentile
- Sklar's theorem states that:
  $P(T \leq T_e, S \leq S_e) = C(F_T(T_e), F_S(S_e))$

Where C is the « **copula** » function



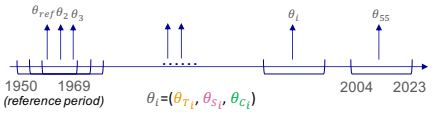
$$\boldsymbol{p} = 1 - F_T(T_e) - F_S(S_e) + C(F_T(T_e), F_S(S_e))$$

Statistical fit

For each grid point & for 20-y period:
Fit different **1d-distributions** (GEV, normal, log-normal) and **copulas** (Archimedean and normal)

For each grid point:
Select one distribution for S and T and one copula for dependence (AIC)

$$\boldsymbol{p}: \theta_{T_{ref}}, \theta_{T_1}, \ldots, \theta_{T_{55}}, \theta_{S_{ref}}, \theta_{S_{21}}, \ldots, \theta_{S_{55}}, \theta_{C_{ref}}, \theta_{C_{21}}, \ldots, \theta_{C_{55}}$$



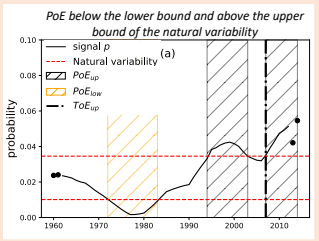
Method applied to one grid point (Vilnius)

1. Emergence of CE probabilities

Time of emergence (ToE) gives the date of a permanent emergence
Limit: No information on significant past variations, highly beneficial for adaptation

➢ new metric: **Period of emergence (PoE)**
"*Periods during which the probability signal emerges significantly from the* ***natural variability (NV)***"

NV: $p_{ref,lower}$ and $p_{ref,upper}$ estimated with the 68% confidence interval of θ_{ref}



2. Statistical drivers of the emergence

Quantifying the contribution of each component (T, S, C) by changing just one parameter:

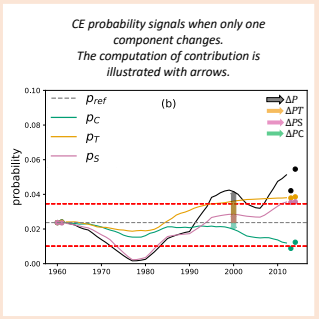
p_T: $\theta_{T_{ref}}, \theta_{T_1}, \ldots, \theta_{T_{55}}, \theta_{S_{ref}}, \theta_{S_{ref}}, \ldots, \theta_{S_{ref}}, \theta_{C_{ref}}, \theta_{C_{ref}}, \ldots, \theta_{C_{ref}}$

p_S: $\theta_{T_{ref}}, \theta_{T_{ref}}, \ldots, \theta_{T_{ref}}, \theta_{S_{ref}}, \theta_{S_{21}}, \ldots, \theta_{S_{55}}, \theta_{C_{ref}}, \theta_{C_{ref}}, \ldots, \theta_{C_{ref}}$

p_C: $\theta_{T_{ref}}, \theta_{T_{ref}}, \ldots, \theta_{T_{ref}}, \theta_{S_{ref}}, \theta_{S_{ref}}, \ldots, \theta_{S_{ref}}, \theta_{C_{ref}}, \theta_{C_{21}}, \ldots, \theta_{C_{55}}$

Contribution metrics:
$\boldsymbol{Contrib_Z} = \frac{\Delta PZ}{\Delta P} 100$
with Z in {T,S,C}

$\boldsymbol{Contrib_{int}} = 100 - Contrib_T - Contrib_S - Contrib_C$



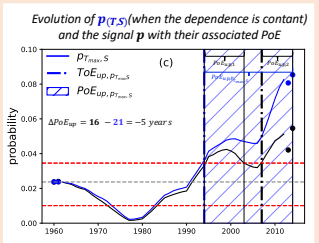
3. Influence of the dependence on the emergence

Quantifying the effect of a dependence change in the signal emergence by keeping the copula parameter constant

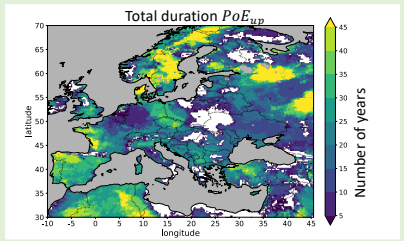
$\boldsymbol{p_{(T,S)}}$: $\theta_{T_{ref}}, \theta_{T_1}, \ldots, \theta_{T_{55}}, \theta_{S_{ref}}, \theta_{S_{21}}, \ldots, \theta_{S_{55}}, \theta_{C_{ref}}, \theta_{C_{ref}}, \ldots, \theta_{C_{ref}}$

Difference of the two signals ($\boldsymbol{p}$ and $\boldsymbol{p_{(T,S)}}$) emergence, through $\Delta\boldsymbol{POE}$:

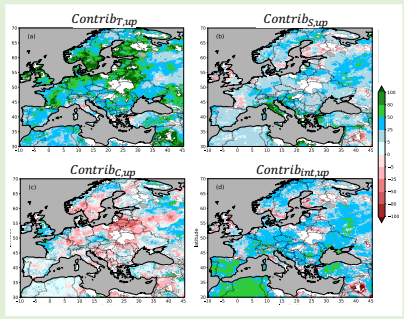
$$\Delta PoE_{up} = PoE_{up,\boldsymbol{p}} - PoE_{up,\boldsymbol{p_{(T,S)}}}$$



Results over Europe

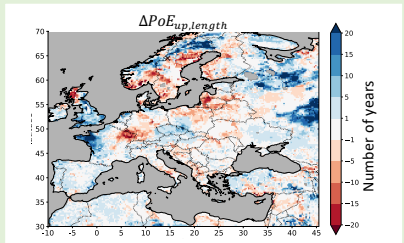


➢ **Significant increase** of hot & dry events over the last few decades.



➢ **Heat index** is the main driver.

➢ **Dependence** change can either contribute positively or negatively to the emergence.



➢ PoE duration is **sensitive** to dependence variations.

Conclusion

Regional contrasts and specificities of hot & dry probability emergence are highligted on the submitted article:

Applicable to any bivariate CE, with any bivariate threshold, and at any location.
R package available on github:

Perspectives

➢ Extend the methodology to **higher dimension** CE

➢ How do **climate models** (e.g., CMIP6) simulate compound events?

➢ Can the emergences be **attributed** to anthropogenic activities?

References

Abatzoglou, J., et al (2020)
doi: 10.1038/s41598-020-60270-5
Hawkins, E., et Sutton, R. (2012)
doi: 10.1029/2011GL050087
Hersbach, et al. (2020)
doi: 10.1002/qj.3803
François, B. et Vrac, M. (2023)
doi: 10.5194/nhess-23-21-2023
Manning, C. et al (2019)
doi: 10.1088/1748-9326/ab23bf
Tootoonchi, F. et al (2022)
doi: 10.1002/wat2.1579
Zscheischler,J., et Seneviratne, S. (2017)
doi: 10.1126/sciadv.1700263